# *Appendix 6-C*

# *Stormwater Design in the Coastal Plain of Virginia*

**Adapted from CSN Technical Bulletin No. 2**
***Stormwater Design in the Coastal Plain of the Chesapeake Bay Watershed***
**(Ver. 1.0: May 1, 2009)**
**Developed by the CSN Coastal Plain Working Group**

# *Appendix 6-C*

# *Stormwater Design in the Coastal Plain of Virginia*

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## 6-C.1.0. WHY THE COASTAL PLAIN IS DIFFERENT?

Most stormwater practices were originally developed in the Piedmont physiographic region and have not been adapted for much different conditions in the coastal plain. Consequently, much of the available stormwater design guidance is strongly oriented toward the rolling terrain of the Piedmont with its defined headwater streams, deeper groundwater table, low wetland density, and well drained soils.

By contrast, stormwater design in the mid-Atlantic coastal plain is strongly influenced by unique physical constraints, pollutants of concern and resource sensitivity of the coastal waters. Implementation of traditional stormwater practices in the coastal plain is severely constrained by physical factors such as flat terrain, high water table, altered drainage, extensive groundwater interactions, poorly-drained soils and extensive wetland complexes. The significance of these constraints is described below.

***Flat Terrain***. The most notable feature of the coastal plain is its uniformly flat terrain which creates several watershed planning and site design challenges. The low relief makes it possible to develop land without regard to topography. From a hydrologic standpoint, flat terrain increases surface water/groundwater interactions and reduces the hydraulic head available to treat the quality of stormwater or move floodwaters through the watershed during the intense tropical storms and hurricanes for which the region is especially prone.

***High Water Table.*** In much of the coastal plain, the water table exists within a few feet of the surface (**Figure 6-C.1**). This strong interaction increases the movement of pollutants through shallow groundwater and diminishes the feasibility or performance of many stormwater control practices.

***Figure 6-C.1. Coastal Plain Water Table***
Source: Chesapeake Bay Stormwater Training Partnership (CBSTP)

***Highly Altered Drainage.*** The coastal plain stream network has been severely altered by 300 years of ditching, channelization, agricultural drainage and mosquito control. The headwater stream network in many coastal plain watersheds no longer exists as a natural system, with most zero order, first order, and second order streams replaced by ditches, canals and roadway drainage.

***Poorly Drained Soils.*** Portions of the coastal plain have soils that are poorly drained and frequently do not allow infiltration to occur. As a result, the coastal plain watersheds contain extensive wetland complexes and have a greater density of wetlands than any other physiographic region in the country (Dahl, 2006). Wetland cover exceeds 25% of many coastal plain watersheds, which exceeds the national average of 7% (Dahl, 2006).

***Very Well-Drained Soils.*** In other parts of the coastal plain, particularly near the coast line, soils are sandy and extremely permeable, with infiltration rates exceeding four inches per hour or more. While these soils are exceptionally good for infiltrating stormwater runoff and promoting recharge, there is a stronger risk of stormwater pollutants rapidly migrating into groundwater. This is a particular design concern, given the strong reliance on groundwater for drinking water supply (discussed next).

***Drinking Water Wells, Septic Systems.*** A notable aspect of the coastal plain is a strong reliance on public or private wells to provide drinking water (USGS, 2006). As a result, ***designers need to consider groundwater protection as a first priority*** when they are considering how to dispose of stormwater. At the same time, development in the coastal plain relies extensively on septic systems or land application to treat and dispose of domestic wastewater. Designers need to be careful in how they manage and dispose of stormwater, so they do not reduce the effectiveness of adjacent septic systems.

***Conversion of Croplands with Land Application*.** Land application of animal manure and domestic wastewater on croplands is a widespread practice across the coastal plain. When this farmland is converted to land development, there is a strong concern that infiltration through nutrient enriched soils may actually increase nutrient export from the site.

***Pollutants of Concern-*** Watershed managers in the Piedmont have historically focused on phosphorus control, which is frequently a limiting nutrient for fresh waters but seldom for coastal waters. By contrast, the key pollutants of concern in coastal plain watersheds are nitrogen, bacteria and metals. These pollutants have greater ability to degrade the quality of unique coastal plain aquatic resources such as shellfish beds, swimming beaches, estuarine and coastal water quality, seagrass beds, migratory bird habitat and tidal wetlands. Yet, the design of many stormwater practices is still rooted in phosphorus control. The design and engineering of stormwater practices need to be greatly modified to achieve greater reductions in nitrogen, bacteria and metals to improve coastal water quality.

***Unique Development Patterns.*** The development patterns of coastal plain watersheds are also unique, with development concentrated around waterfronts, water features and golf courses rather than around an urban core. The demand for vacation rental, second home and retirement properties also contributes to sprawl-type development.

***Shoreline Buffers and Critical Areas.*** Virginia has special land use criteria for locally designated coastline and river-edge resource lands in the coastal plain, known as the Chesapeake Bay Preservation Areas (CBPAs). They regulations applicable to CBPAs strongly influence how stormwater practices are designed and located. In addition, the predominance of shoreline development often means that stormwater must be provided on small land parcels a few hundred feet from tidal waters. Consequently, many development projects within CBPAs must rely on micro-scale stormwater control practices to comply with the special state and local requirements.

***The Highway as the Receiving System.*** The stormwater conveyance system for much of the coastal plain is frequently tied to the highway ditch system, which is often the low point in the coastal plain drainage network. New upland developments often must get approvals from highway authorities to discharge to their drainage system, which may already be at or over capacity with respect to handling additional stormwater runoff from larger events. The prominence of the highway drainage network in the coastal plain has several implications, the greatest of these is that designers have to obtain both a local government and VDOT approval for their project, which often results in conflicting design requirements.

***Sea Level Rise.*** Another unique aspect of the tidal waters of the coastal plain is the forecasted rise in sea level over the next 30 to 50 years as a result of land subsidence and climate change. The consensus (conservative) predictions are for sea level in the Chesapeake Bay to rise at least a foot in the coming decades, and perhaps two feet by the end of the century. This large change in average and storm elevations in the transition zone between tidal waters and the shoreline development only a few feet above it has design implications for the choosing where to discharge treated stormwater.

***Hurricanes and Flooding*.** Coastal communities face unique challenges when it comes to handling flooding events. First, due to their location on the coast, they are subject to rainfall intensities that are 10% to 20% greater for the same design storm event compared to sites further inland. Second, the flat terrain lacks enough hydraulic head to quickly move water out of the conveyance system (which may be further complicated by backwater effects of tidal surges). Additionally, large tidal surges may cause significant flooding with no precipitation present (see **Figure 6-C.2** below).

## 6-C.2.0. GENERAL COASTAL PLAIN STORMWATER DESIGN PRINCIPLES

The following initial guiding principles are offered on the design of stormwater practices in the coastal plain:

- Use micro-scale and small-scale practices for development projects within 500 feet of shoreline or tidal waters.
- Exploit opportunities for upland runoff reduction prior to using end of channel/pipe practices such as wet ponds, and incorporate essential coastal plain design features within any ponds employed.
- Keep all stormwater practices out of the riparian buffer area, except for the use of conservation filters at their outer boundary.

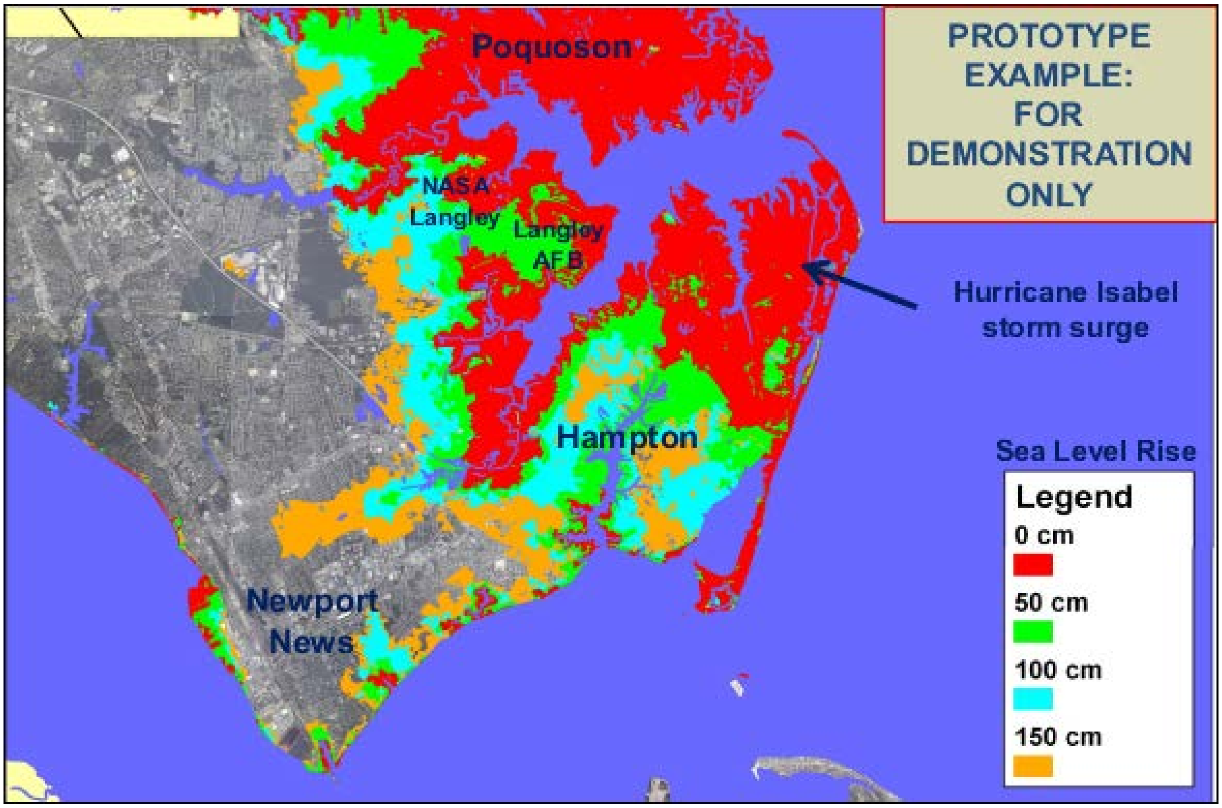


***Figure 6-C.2. Hurricane Flood Prediction Model with Reference to Potential Sea Level Rise***
Source: Virginia Institute of Marine Science and Noblis, Inc.

- Relax some design criteria to keep practice depths shallow and respect the water table.
- Emphasize design factors that can increase bacteria removal (and certainly not exacerbate bacteria problems).
- Promote de-nitrification to maximize nitrogen removal, by creating adjacent anaerobic and aerobic zones adjacent to one another in either the vertical or lateral direction.
- Use plant species that reflect the native coastal plain plant community and, in particular, can survive well in a high salinity environment.
- Take a linear design approach to spread treatment along the entire length of the drainage path, from the rooftop to tidal waters, maximizing the use of in-line treatment in the swale and ditch system.
- Consider the effect of sea level rise on future elevations of stormwater practices and infrastructure. In some cases, it may make more sense to utilize site design to "raise the bridge" by increasing the vertical elevation of building pads at coastal plain development sites.

## 6-C.3.0. SIZING STORMWATER PRACTICES IN THE COASTAL PLAIN

The following factors influence the sizing of stormwater practices in the coastal plain.

### 6-C.3.1. Higher Coastal Plain Nutrient Concentrations on Stormwater Runoff

A recent data analysis indicates there is a strong statistical difference in the nutrient concentrations between the coastal plain and piedmont physiographic regions in Virginia. Hirschman et al (2008) analyzed more than 753 storm events and found that median event concentrations of nutrients are 15% to 25% higher in the coastal plain, as compared to the piedmont (see **Table 6-C.1**). The reason for the higher nutrient concentrations is unclear, but it may be related to the greater stormwater-groundwater interaction that occurs, along with possible soil nutrient enrichment due to land application and septic system leachate.

***Table 6-C.1. Comparison of Nutrient Storm Event Mean Concentrations in the Virginia Piedmont versus Coastal Plain (N=753 storm events)***

| Nutrients | Coastal Plain | Piedmont |
|---|---|---|
| Total Nitrogen [1] | 2.13 mg/l | 1.70 mg/l |
| Total Phosphorus | 0.27 mg/l | 0.22 mg/l |
| [1] The EMC for residential TN in Coastal plain is 2.96 mg/l | | |

Source: Appendix G of Hirschman et al 2008

### 6-C.3.2. Greater Water Quality Storm Events

Rainfall intensities are consistently greater in the coastal plain than in the piedmont. Rainfall Frequency Spectrum Analyses (RFSA) were conducted at numerous weather stations in Maryland to statistically determine the 90% storm event that defines the water quality volume (MDE, 2000). The analysis determined that while the 90% storm was 1.0 inch or less in the Piedmont stations and further west, it ranged from 1.1 to 1.2 inches in the coastal plain, with the greatest values near the coast.

Virginia had the Center for Watershed Protection conduct RFSAs at five locations around the Commonwealth (Abingdon, Lynchburg, near Harrisonburg, Richmond, and Reagan International Airport in Northern Virginia) in order to determine the variation in rainfall and establish a 90$^{th}$ percentile rainfall event for regulatory purposes. However, the study neglected to include a Tidewater location. The average result was 1.14 inches of rainfall. The Department decided to round that number down to the 1-inch rainfall and establish that as the statewide water quality design storm event. However, pursuant to the Virginia Stormwater Management Act, local governments are authorized to establish more stringent regulatory criteria. For example, a locality with a higher 90$^{th}$ percentile storm event (e.g., 1.2 inches) could establish that as the local water quality storm event, based on a localized or regional RFSA. The Virginia Runoff Reduction Method spreadsheet could be adapted to reflect the local rainfall amount.

### 6-C.3.3. Channel Protection Exemption?

Another key issue, subject to some debate, relates to whether a channel protection volume is needed to protect coastal plain stream channels from erosion. The 2000 *Maryland Stormwater Design Manual* contained two specific exemptions from channel protection for portions of the coastal plain: (a) the entire Eastern Shore of Maryland and (b) any direct discharges or outfalls to tidal waters. The Virginia Stormwater Management Regulations do not contain any specific exemptions for the coastal plain, and the stormwater regulations proposed by the Delaware Department of Natural Resources and Environmental Control *require* channel protection for coastal plain streams. While the tidal outfall exemption is reasonable, ***the growing body of geomorphic research on coastal plain streams strongly suggests that they should not automatically be exempted from channel protection***.

### 6-C.3.4. The Prevalence of Wet Ponds

***Figure 6-C.3. Wet Pond***

Wet ponds (**Figure 6-C.3**) are extremely popular in coastal plain communities, since excavated sediments can be used for fill elsewhere in the site, and the pond can also be used to temporarily store floodwater from larger design storm events. According to a major survey by Law (2008), wet ponds were the most common stormwater practice used in the coastal plain, with 81% of communities reporting their use. In some tidewater communities with high water tables, such as Newport News, VA, wet ponds treat 80% of the total land area to which stormwater practices are applied.

Since most coastal wet ponds are excavated well below the water table, they are strongly influenced by groundwater. Recent research profiled in **Section 6.0** of this Appendix indicates that coastal plain "dug-out wet ponds" have diminished nutrient removal capability (particularly for nitrogen) and extremely low rates of annual runoff volume reduction. In addition, under certain conditions, coastal plain wet ponds can create stagnant water nuisance conditions (including harmful algal blooms, mosquito breeding, etc.). Field studies have also revealed that many coastal plain wet ponds are frequently installed without the design features necessary to ensure their effective function.

### 6-C.3.5. Comparative Reduction of Runoff, Nitrogen and Bacteria

As noted earlier, the pollutants of concern in the coastal plain tend to be slightly different, which has a strong influence on the selection of stormwater practices. **Table 6-C.2** presents the most recent estimates of the runoff volume reduction, nitrogen removal and bacterial removal rates for the 15 classes of non-proprietary stormwater control practices approved by the Department. As can be seen, there is significant variability in the capability of different classes of stormwater control practices to reduce runoff and provide nitrogen or bacteria reduction. It is worth noting that while there a wide range of studies examining nitrogen EMC reduction rates of BMPs, relatively few have been conducted in the coastal plain. The situation is even worse for bacteria, where the actual data on *f. coli* or *e. coli* removal is sparse for all physiographic regions (Schueler, 2000 and 2007).

*Table 6-C.2 Comparative Runoff Reduction, Nitrogen and Bacteria Removal*

| Practice | Annual Runoff Reduction (%) [1] | Nitrogen EMC Removal (%) [2] | Bacteria Removal [3] |
|---|---|---|---|
| **Constructed Wetland** | 0 | 25 to 55 [4] | 60 |
| **Bioretention** | 40 to 80 | 40 to 50 | 40* |
| **Rain Tank/Cistern** | 15 to 45 [5] | 0 | NA |
| **Wet Swale** | 0 | 25 to 35 | 0 |
| **Dry Swale** | 40 to 60 | 25 to 35 | 25* |
| **Rooftop Disconnection** | 25 to 50 | 0 | NA [6] |
| **Permeable Pavers** | 45 to 75 | 25 | ND [7] |
| **Filter Strips** | 25 to 50 | 15 | 20* |
| **Sand Filters** | 0 | 30 to 45 | 40 |
| **Infiltration** | 50 to 90 | 15 | 40* |
| **Urban Bioretention** | 40 | 40 | 40* |
| **Compost Amendments** | 25 to 50 | 0 | NA |
| **Green Roofs** | 45 to 60 | 0 | NA |
| **Wet Ponds** | 0 | 30 to 40 | 70 |
| **Dry ED Ponds** | 0 to 15 | 10 | 35 |
| **Grass Channel** | 10 to 20 | 20 | -25 |

[1] Annual average runoff reduction as reported in Hirschman et al (2008)
[2] Change in stormwater event mean concentration (EMC) as it flows through the practice, as reported In CWP (2008). Total mass reduction is product of EMC reduction and runoff reduction.
[3] Bacteria removal rates as reported by Schueler et al, 2007. An asterisk denotes where monitoring Data is limited, and estimates should be considered extremely provisional.
[4] Where a range of numbers are shown in the cell, this refers to the Level 1/Level 2 design features as outlined in Hirschman et al. (2008).
[5] Runoff reduction can be increased if rain tanks are coupled with a secondary runoff reduction Practice (rain garden, filter path or front-yard retention).
[6] NA indicates the practice is not designed for bacterial removal or is located far up in treatment pathway such that bacteria source areas are largely absent (e.g., green roofs and cisterns)
[7] ND means no data is available.

In some cases, practices such as grass channels or ditches have been found to have low or negative rates for bacteria removal (Mallin et al, 2001). Given the limited bacteria data, the numbers shown in **Table 6-C.2** should be considered provisional, and designers should maximize the following design factors to enhance bacteria removal (adapted from Schueler, 2000):

- Create high light conditions to promote UV in areas of standing water.
- Design to prevent re-suspension of bottom sediments in treatment systems.

- Choose vegetation other than turf around ponds and wetlands to make access more difficult for geese and waterfowl.
- Use shallow wetlands and benches to create natural micro-predators for bacteria. However, at least a portion of the wetland area should be deep enough to avoid freezing in winter. Furthermore, the wetland surface should be exposed enough to result in high enough water temperatures in the summer to become anaerobic.
- Add a layer of organic matter into sand filter media.
- Avoid the use of grass channels (dry or wet swales are preferred).
- Maximize infiltration and filtration of runoff through soils.
- Maintain specified setbacks to prevent interaction of stormwater and septic drainfields and, if possible, connect household waste discharges to the local sanitary sewer and wastewater treatment plant.
- Use Vegetated Filter Strips at the edge of riparian buffer areas.
- Address all bacteria source areas.

### 6-C.3.6. Hotspot Concerns in the Coastal Plain

Stormwater hotspots are operations or activities that are known to produce higher concentrations of runoff pollutants and/or have a greater risk for spills, leaks or illicit discharges. Given that many portions of the coastal plain rely on groundwater as a primary source of drinking water, it is important to take steps to minimize the risk of groundwater contamination by polluted stormwater. A list of potential land uses or operations that may be designated as a stormwater hotspot is provided in the Virginia Stormwater Design Specification No. 8 (Infiltration).

Communities should carefully review development proposals to determine if any future activity on all or a portion of the site is likely to be designated as a stormwater hotspot. If so, stormwater treatment and pollution prevention practices must then be implemented at the hotspot to prevent contamination of surface or groundwater, particularly if it discharges to a drinking water source. Depending on the toxicity of the hotspot discharge, one or more of the following management strategies may be required:

- ***Stormwater Pollution Prevention Plan (SWPPP).*** This plan is required as part of an industrial, municipal, or general construction stormwater permit, and it outlines pollution prevention and treatment practices that will be implemented to minimize polluted discharges from the site.
- ***Restricted Infiltration.*** A minimum of 50% of the total Treatment Volume must be treated by a filtering or bioretention practice prior to allowing any infiltration to occur. Portions of the site that are not associated with the hotspot generating area should be diverted away and treated by an acceptable stormwater control practice.
- ***Infiltration Prohibition.*** The risk of groundwater contamination from spills, leaks or discharges is so great at hotspot sites that infiltration of stormwater runoff is ***prohibited.*** In these cases, an alternative stormwater control practice such as a closed bioretention area, sand filter or constructed wetland must be used to filter runoff before it reaches surface or groundwater.

### 6-C.3.7. Altered Drainage Systems

When designing stormwater management systems in the Coastal Plain, it is important to recognize that the original drainage patterns in a given watershed may have been significantly altered through stream channelization and/or the creation of constructed storm drainage systems (**Figure 6-C.4**). Thus, not only is much of the original surface storage lost, but the drainage network is much more hydraulically "efficient," as compared to a more natural wetland/stream system. In addition, most constructed drainage systems have been designed to prevent crop damage from standing water, not as conveyance systems based on a specific storm frequency. For example, it has been estimated that the typical constructed drainage channel in Delaware's Coastal Plain only has the capacity to convey the runoff from a 1-year to 2-year storm event under *pre-development conditions*. Further exacerbating this situation is the fact that there is typically no defined floodplain in the lower coastal plain to contain flows that exceed the capacity of these drainage channels.

***Figure 6-C.4. Channelized Section of Four Mile Run, Fairfax County, VA.***

Since local jurisdictions have not traditionally treated these constructed channels the same as natural streams, they often do not have floodplain ordinances or other controls in place to prevent potential impacts to adjacent properties under historic development patterns. Therefore, watersheds having a large percentage of altered drainage systems may require relatively stringent over-management techniques if adequate runoff reduction methods are not feasible. In cases where regulatory floodplains have not been established, one option for new development would be to provide adequate lot-free open space adjacent to altered drainage systems to accommodate out-of-bank flooding occurrences. Although it may not be feasible to extend the limits of this open space to accommodate the 100-year storm event, it seems reasonable to accommodate at least the 10-year storm in order to minimize the impacts of more frequent flooding events.

### 6-C.3.8. Discharges to Wetlands

Recent research has clearly shown that, even at extremely low levels of land development, direct and indirect stormwater discharges can have a deleterious impact on sensitive streams and wetlands (Wright et al 2007, Cappiella et al 2006). Consequently, a greater level of protection is needed to safeguard these important ecosystems from stormwater discharges, as follows:

- Define a series of sensitive wetland types that merit special protection (e.g., bogs, fens and others – see Wright et al, 2007).
- Explicitly prohibit the use of natural wetlands to provide stormwater treatment of any kind.
- Require full runoff volume reduction up to the amount of the Channel Protection Volume prior to discharge to a sensitive wetland down-gradient from the development site.
- Require modeling and monitoring analyses to confirm that no changes occur in the post-development hydroperiod in sensitive wetlands, which is operationally defined as no more than 6 inches of additional water level fluctuation for a 1-inch rainfall event.

## 6-C.4.0. APPLICABLE STORMWATER TREATMENT PRACTICES

This section evaluates the comparative applicability of the range of potential non-proprietary stormwater control practices, and classifies them as preferred, acceptable or restricted, as shown in **Table 6-C.3**.

***Table 6-C.3. Comparison of the Applicability of Stormwater Practices for Coastal Plain***

| Stormwater Control Practice | Suitability for the Coastal Plain | Virginia Design Spec No. | Design and Implementation Notes |
|---|---|---|---|
| **Rooftop Disconnection** | Preferred | **1** | Via front-yard bioretention |
| **Sheet Flow to Vegetated Filter Strips and Conserved Open Space** | Preferred | **2** | Conservation filters to stream or shoreline buffers |
| **Rainwater Harvesting** | Preferred | **6** | Use above-ground tanks |
| **Shallow Dry Swale** | Preferred | **10** | Relaxed filter bed and water table depths; conduct soil nutrient testing |
| **Wet Swale** | Preferred | **11** | Can use on-line and off-line cells |
| **Constructed Wetland** | Preferred | **13** | Use shallow, linear, multiple-cell designs |
| **Permeable Pavement** | Acceptable | **7** | Use an underdrain when the infiltration rate is low or the water table is high |
| **Shallow Bioretention** | Acceptable | **9** | Relaxed filter bed and water table depths; conduct soil nutrient testing |
| **Soil Compost Amendments** | Acceptable | **4** | For B.C, and D soils, must be at least 2 feet above the water table |
| **Green Roofs** | Acceptable | **5** | Use coastal vegetation species selection |
| **Small Scale Infiltration** | Acceptable | **8** | Use wide and shallow designs; max. contributing drainage area is 20,000 sq. ft. of impervious cover |
| **Urban Bioretention** | Acceptable | **9a** | Use curb extensions, foundation planters and tree pits |
| **Filtering Practices** | Acceptable | **12** | Perimeter or non-structural sand filters are the most practical options |
| **Wet Pond** | Acceptable | **14** | See **Section 6** of this Appendix |
| **Grass Channel** | Restricted | **3** | Achieves poor bacteria removal |
| **Large Scale Infiltration** | Restricted | **8** | Depends on the soil infiltration rate and the nutrient composition in the soil |
| **Dry Ext. Detention Pond** | Restricted | **15** | Constrained by min. hydraulic head rqmts |

## 6-C.5.0. SPECIFIC COASTAL PLAIN DESIGN CRITERIA FOR STORMWATER CONTROL PRACTICES

The ensuing discussion highlights some possible design adaptation for the coastal plain, and should be considered a starting point and not an ending point

### 6-C.5.1. Criteria for *Preferred* Stormwater Control Measures

These stormwater practices possess two properties: (1) they are widely feasible at most development sites in the coastal plain (with some design adaptations), and (2) they have a high rate of runoff volume reduction and/or a strong capability to remove pollutants of concern in the coastal plain (e.g., nitrogen, bacteria, etc.).

***Rooftop Disconnection.*** Rooftop disconnection is strongly recommended for all residential lots with areas of less than 6,000 square feet, particularly if it can be combined with a secondary micro-practice to increase runoff reduction and prevent seepage problems. (See Virginia Stormwater Design Specification No. 1 for the four primary micro-practice options.) The disconnection corridor should have a minimum slope of 1% and 2 feet of vertical separation to the water table.

***Sheet Flow to Vegetated Filter Strips and Conserved Open Space*.** The use of conservation filter strips is highly recommended in the coastal plain, particularly when runoff discharges to the outer boundary of the shoreline, stream or wetland buffer, either as sheet flow or a concentrated discharge. Grass filter strips can also be used to treat runoff from small areas of impervious cover (e.g., less than 5,000 square feet). However, in both cases the water table must be at lest 18 inches below the ground surface, Depending on surface flow conditions, the filter strip must have a gravel diaphragm, a pervious berm or an engineered level spreader conforming to the new requirements outlined in Virginia Stormwater Design Specification No. 2.

***Rainwater Harvesting*** (Virginia Stormwater Design Specification No. 6)**.**

- In the coastal plain, above ground tank designs are preferred to below ground tanks**.**
- Tanks should be combined with automated irrigation, front yard bioretention or other secondary practices to maximize runoff volume reduction.

***Permeable Pavement*.** Experience in North Carolina has shown that properly designed and installed Permeable Pavement systems (Virginia Stormwater Design Specification No. 7) can work effectively in the demanding conditions of the coastal plain, as long as underlying soils are moderately to highly permeable.

- Designers should avoid the use of non-underdrain permeable pavement systems at stormwater hotspot facilities and in areas known to provide groundwater recharge to any aquifer used as a water supply.
- Designers should ensure that the vertical distance from the bottom of the permeable pavement system to the top of the water table is at least 2 feet.

- If an underdrain is used beneath permeable pavement, a minimum 0.5% slope must be maintained to ensure positive drainage.
- In order to avoid clogging, avoid using permeable pavement if the site will be exposed to blowing sand (i.e., near coastal sand dunes).

***Bioretention*.** Either the Level 1 (underdrain) or Level 2 (infiltration) design can be used for bioretention, depending on soil permeability and local water table conditions. The following design adaptations can help make bioretention work better in the coastal plain:

- A linear approach to bioretention – using multiple cells leading to the ditch system – helps conserve hydraulic head.
- The minimum depth of the filter bed can be relaxed to from 18 to 20 inches if hydraulic head or high water table issues exist.
- Bioretention media should be secured from an approved vendor to ensure nutrient content of the soil and compost are within acceptable limits. The use of on-site soils in the coastal plain is discouraged due to their probable nutrient enrichment, unless soil tests have been performed and show otherwise.
- To reduce the vertical footprint, (1) to limit surface ponding to from 6 to 9 inches, and (2) save additional depth by shifting to turf rather than a mulch cover.
- The minimum depth from the bottom of the bioretention practice to the seasonally high groundwater table may be as little as 1 foot, as long as the bioretention area is equipped with a large diameter underdrain (e.g., 6 inches in diameter) that is only partially efficient at dewatering the bioretention bed.
- It is important to maintain a slope of at least 0.5% for the underdrain to ensure positive drainage, and connect the underdrain to a ditch or the conveyance system.
- The mix of plant species selected should reflect native coastal plain plant communities and should be more wet-footed and salt tolerant than for typical Piedmont applications. See Virginia Stormwater Design Specification No. 9 for a list of plant species suitable for use in coastal bioretention practices.

***Dry Swale*.** Dry Swales (Virginia Stormwater Design Specification No. 10) work well at many coastal plain sites, but they require several design adaptations to improve their feasibility and performance, consistent with the following:

- The minimum depth of the filter bed may be relaxed to from 18 to 20 inches, if hydraulic head or high water table conditions issues exist.
- The minimum depth to the seasonally high water table can be reduced to one foot, as long as the Dry Swale area is equipped with an underdrain
- It is important to maintain a slope of at least 0.5% for the underdrain to ensure positive drainage, and connect the underdrain to a ditch or the conveyance system.
- Designers should not try to apply Dry Swales to marginal sites, where wet swales or linear wetlands would work better (e.g., where the groundwater table is less than 30 inches below the swale invert).

***Wet Swales*.** Wet Swales (Virginia Stormwater Design Specification No. 11), essentially linear wetlands consisting of a series of on-line or off-line storage cells, work well in areas with a high water table. Designers should design cells such that underlying soils are typically saturated but do not cause standing water between storm events. It may also be advisable to incorporate sand or compost into the surface soils to promote a better growing environment. Wet swales should be planted with native wet-footed species, such as sedges or wet meadows. Wet swales are not recommended in residential areas due to concerns about mosquito breeding.

***Constructed Wetlands*.** Constructed Wetlands (Virginia Stormwater Design Specification No. 13) are an ideal stormwater control measure for the flat terrain, low hydraulic head and high water table conditions found at many coastal plain development sites. The following design adaptations can make them more effective:

- Shallow, linear and multiple-cell wetland configurations are preferred.
- Deeper basin configurations, such as the pond/wetland system and the extended detention wetland have *limited application* in the coastal plain.
- It is acceptable to excavate up to 6 inches below the seasonally high groundwater table to provide the requisite hydrology for wetland planting zones, and up to 3 feet below the water table for micropools, forebays and other deep pool features.
- The volume below the seasonably high water table is acceptable for the Treatment Volume, as long as the other primary geometric and design requirements for the wetland are met (e.g., flow path, microtopography, etc.).
- Plant selection should focus on native species that are wet-footed and can tolerate some salinity.
- A greater range of coastal plain tree species can tolerate periodic inundation, so designers should consider creating forested wetlands, using species such as Atlantic White Cedar, Bald Cypress and Swamp Tupelo.
- The use of flashboard risers is recommended to control or adjust water elevations in wetlands constructed on flat terrain.
- The regenerative conveyance system is particularly suited for coastal plain situations where there is a significant drop in elevation from the channel to the outfall location (see Virginia Stormwater Design Specification No. 11: Wet Swale).

### 6-C.5.2. Criteria for *Acceptable* Stormwater Control Measures

This group of stormwater control measures can work at many sites in the coastal plain, but they either require major design adaptations or have a low-to-moderate capability to reduce the coastal pollutants of concern.

***Soil Compost Amendments*.** Designers should evaluate drainage and water table elevations to ensure the entire depth of incorporated Soil Compost Amendments (Virginia Stormwater Design Specification No. 4) will not become saturated (i.e., maintain a minimum separation depth of 2 feet from the seasonally high groundwater table). Compost amendments are most cost effective when used to boost the runoff reduction capability of grass filter strips, grass channels and areas receiving runoff from rooftop disconnections.

***Vegetated Roofs*.** Vegetated Roofs (Virginia Stormwater Design Specification No. 5) may be used in the coastal plain, but their effectiveness is somewhat limited since rooftops are not a major runoff source area for nutrients or bacteria, the key coastal plain pollutants of concern. Designers should consult with a qualified botanist or landscape architect to choose the most appropriate plant material, such as indigenous varieties of grass and *sedum* species, that can tolerate drought and salt spray.

***Small-Scale Infiltration*****.** The **c**oastal plain is an acceptable environment for micro-infiltration and small-scale infiltration practices (Virginia Stormwater Design Specification No. 8), particularly if designers choose to infiltrate less than the full Treatment Volume in a single practice (and use secondary practices to achieve the remaining runoff reduction or treat the remaining volume). Some other design modifications for small scale infiltration in the coastal plain include the following:

- Designers should maximize the surface area of the infiltration practice, and keep the depth of infiltration to less than 24 inches.
- Where soils are extremely permeable (more than 4 inches per hour), shallow bioretention is a preferred alternative.
- Where soils are more impermeable (i.e., marine clays with permeability of less than 0.5 inches/hour), designers should probably shift to the use of bioretention *with underdrains*.
- The minimum depth to the water table should be kept to at least 2 feet.

***Urban Bioretention.*** Three forms of bioretention for highly urban areas can work acceptably within the coastal plain – (1) stormwater curb extensions, (2) expanded tree planters, and (3) foundation planters – particularly when above-ground design variants are used (see Appendix A of Virginia Stormwater Design Specification No. 9). The general coastal plain design modifications for regular bioretention should also be consulted (see Virginia Stormwater Design Specification No. 9).

***Filtering Practices*****.** The flat terrain, low hydraulic head and high groundwater table of the coastal plain make several of the filter designs (Virginia Stormwater Design Specification No. 12) difficult to implement. However, the perimeter sand filter and the non-structural sand filter have the least hydraulic head requirements and can work effectively at many small coastal plain sites, when the following design adaptations are made:

- The combined depth of the underdrain and sand filter bed may be reduced to from 24 to 30 inches.
- Designers may wish to maximize the length of the stormwater filter or provide treatment in multiple connected cells.
- The minimum depth to the seasonally high water table may be reduced to 12 inches, as long as the filter is equipped with a large diameter underdrain (e.g., 6 inches in diameter) that can de-water the bed if the groundwater mounds up.
- It is important for the underdrain to (1) have at least a 0.5% slope to ensure positive drainage and (2) be connected to the ditch or stormwater drainage system.

***Wet Ponds*****.** A major research review, which is provided in **Section 6** of this Appendix, was conducted to verify the performance of Wet Ponds (Virginia Stormwater Design Specification No. 14) in the coastal plain. The following are the key findings:

- Expected nutrient removal rates are slightly reduced in the coastal plain, due to the influence of groundwater.
- Certain design features are essential to achieving optimal nutrient removal rates (e.g., multiple cells, benches, flow path, etc.).
- Additional design features (e.g., pond landscaping, bubblers/floating islands, etc.) could improve pollutant removal functions.
- Wet ponds could produce and or export harmful algal blooms if they interact with brackish groundwater or surface waters.

Consequently, special design recommendations are proposed for coastal plain wet ponds, as outlined in **Table 6-C.4** below. Where land is available, shallow constructed wetlands are a preferred over wet ponds in coastal plain environments with high water tables.

***Table 6-C.4. Level 1 and 2 Wet Pond Design Guidance: Coastal Plain***

| Level 1 Design (RR:0 [1]; TP:45; TN:20) | Level 2 Design (RR:0; TP:65; TN:30) |
|---|---|
| $T_v$ = (1.0) (Rv) (A) / 12 | $T_v$ = 1.5 (Rv) (A) / 12 |
| Single pond cell (with a forebay) | Wet extended detention [2] or multiple-cell design [3] |
| Flow path = 1:1 or more [4] | Flow path = 1.5:1 or more |
| Standard aquatic benches | Wetlands comprise more than 10% of pond area |
| Turf in pond buffers | Pond landscaping to discourage geese |
| No internal pond mechanisms | Aeration (preferably bubblers that extend to or near the bottom or are on floating islands |
| Maintenance access to the forebay/riser | Maintenance access to the forebay/riser |
| [1] Runoff reduction can be computed for wet ponds designed for water reuse and upland irrigation<br>[2] Extended Detention provided to meet the water quality volume<br>[3] At least three internal cells including the forebay<br>[4] In the case of multiple inlets, the flow path is measured for the dominant inlets (that compromise 80% or more of total pond inflow) | |

## 6-C.5.3. *Restricted* Stormwater Control Measures

The last group of stormwater management practices has limited feasibility in the coastal plain and or poor removal capability for the pollutants of concern. In most cases, these practices are not recommended to function as the primary stormwater control at coastal plain development sites.

***Grass Channel.*** Although Grass Channels (Virginia Stormwater Design Specification No. 3) work reasonably well in the flat terrain and low hydraulic head conditions of many coastal plain sites, they have very poor nutrient and bacteria removal rates. A Grass Channel should not be used as a stand-alone system. Dry Swales or Wet Swales are a much superior option to the Grass Channel, unless the soils are in the highly permeable Hydrologic Soil Group “A”. In these situations, apply the following criteria:

- The minimum depth to the seasonally high water table may be reduced to 18 inches.
- A minimum slope of 0.5% must be maintained to ensure positive drainage.
- The Grass Channel may have off-line cells and should be connected to the ditch or other stormwater drainage system.

***Large-Scale Infiltration*****.** Large scale Infiltration, defined as individual Infiltration practices that serve a contributing drainage area of from 20,000 to 100,000 square feet of impervious cover, can work well in coastal plain sites where soils have an infiltration rate between 0.5 to 4.0 inches per hour. Where soils are extremely permeable (more than 4 inches per hour), a two-cell system (consisting of a shallow bioretention or filtering practice draining to the infiltration practice) should be used to provide for pollutant filtering prior to introduction into groundwater. Infiltration (Virginia Stormwater Design Specification No. 8) should *not* be used if the site is a designated stormwater hotspot.

***Extended Detention Ponds*****.** The lack of sufficient hydraulic head and the high groundwater table at many coastal plain sites severely constrain the application of Extended Detention (ED) Ponds (Virginia Stormwater Design Specification No. 15). Excavating ED ponds below the water table creates unacceptable conditions within the basin. No credit for the Treatment Volume may be taken for the water volume below the seasonally high water table. In general, ***shallow constructed wetlands are a superior option to ED ponds for the coastal plain environment****.*

## 6-C.6.0. TECHNICAL UPDATE ON COASTAL PLAIN WET POND RESEARCH AND IMPLICATIONS FOR DESIGN

The information in this section is an outgrowth from a Tidewater Virginia workshop on stormwater Wet Pond design held on March 22-23, 2009, where there was considerable debate about the original recommendation to restrict credit for the Treatment Volume ($T_V$) only to the pool storage volume that is above the seasonably high water table. The technical documentation for the proposed restriction, as initially drafted, would have restricted the feasibility of the most widely-used stormwater control measure in the Tidewater area of Virginia. Workshop participants requested that this groundwater-limited restriction be reconsidered. In that context, this section summarizes recent Wet Pond research and presents the basis for refined design and sizing criteria for Wet Ponds used in the coastal plain.

### 6-C.6.1. Review of Existing Research on Coastal Plain Wet Ponds

Several recent studies and reviews have explored the performance of wet pond performance in coastal plain conditions, particularly as performance is affected by the influence of groundwater (Mallin et al, 2002, Drescher et al, 2007, Harper and Baker, 2007, DeLorenzo and Fulton, 2009, Hirschman and Woodworth, 2009). These studies expand on the original review of the influence of groundwater on Wet Ponds developed by Schueler (2001). **Table 6-C.5** below summarizes the nine coastal plain Wet Pond pollutant removal performance studies, all of which had some groundwater interaction.

The basic findings from this review include the following:

- It was not possible to statistically compare the population of Wet Ponds in the *National Stormwater Pollutant Removal Database* that are influenced by groundwater with those that are not. The primary reasons relate to small sample size, the variability in the degree of coastal plain groundwater interaction, and considerable differences in design, sizing and residence time among the individual wet ponds studied. Nevertheless, it is evident that the groundwater influence in coastal plain Wet Ponds constrains the maximum degree of nutrient removal they can provide, as compared Wet Ponds in other physiographic regions Virginia where groundwater does not have so much influence.

***Table 6-C.5. Review of Coastal Plain Wet Pond Nutrient Removal Performance***

| Study [3] | Location | Name | TP | TN |
|---|---|---|---|---|
| Mallin, 2002 | Wilmington NC | Ann McCrary | 23 [2] | (-3.5) |
| Mallin 2002 | | Silver Stream | 58 | 40 |
| Mallin, 2002 | | Echo Farms | (-35) | (-41) |
| Gain, 1996 [1] | Orlando, FL | FDOT | 30 | 16 |
| Kantrowitz 1995 [1] | Florida | St Joes | 40 | 23 |
| McCann 1995 [1] | Orlando, FL | Greenwood | 62 | (-11) |
| Rushton, 1997 [1] | Tampa Bay, FL | TB Detention | 57-62 | 16-33 |
| Messersmith 2007 | South Carolina | 5 cell pond | 70 | 40 |
| Messersmith, 2007 | South Carolina | 1 cell pond | (-2) | (-5) |
| **Virginia LEVEL 1 [4] Criteria** | | | **50** | **30** |
| **Virginia LEVEL 2 Criteria** | | | **75** | **40** |

[1] As reported in the CWP *National Stormwater Pollutant Removal Database (2008)*
[2] The removal measured as the monthly concentration entering and leaving pond (N=29)
[3] Due to differences in pond design, sizing and stormwater monitoring protocols, the nine studies cannot be either directly compared to each other or aggregated to compute an overall average
[4] Nutrient event mean concentration (EMC) reduction rates reported in the Virginia Wet Pond Design Specification (No. 14)

- The analysis of individual coastal plain studies shows that Wet Pond performance clearly falls into one of two general groups. The first group consists of relatively standard Wet Pond designs that do not appear to be capable of meeting either Virginia Level 1 or Level 2 performance criteria for N and P removal (see the shaded cells in **Table 6-C.5** above). As a group, these Wet Ponds have low or even negative nutrient removal rates.

- The second group of Wet Ponds performed much better and could generally meet the Level 1 removal rates and, sometimes, the Level 2 removal rates. This group of Wet Ponds incorporated much more sophisticated design features and geometry. For example, the Silver Stream pond had a length-to-width ratio of nearly 18:1, two cells, a 2-foot depth, and extensive macrophyte and wetland cover (Mallin et al, 2002). Similarly, the Greenwood pond was composed of three cells, was oversized (1.25 inches of storage), contained extensive wetland benches and aeration fountains, and provided for water reuse (McCann, 1995). The Tampa Bay pond was retrofitted to increase detention time from 1 to 7 days, and included wet extended detention and wetland design elements (Rushton, 1997). The last top performer was a five-cell Wet Pond in South Carolina, with a very long residence time and extensive wetland elements (Messersmith, 2007).

- Another important study was conducted by Harper and Barker (2007). They examined the relationship between detention time and nutrient removal in a population of 19 Florida Wet Ponds and urban lakes with average residence times ranging from 1 to 500 days. All of these ponds and lakes were presumed to have a high degree of groundwater interaction. Harper and Barker found a strong statistical relationship between detention time and mass removal rate, with $r^2$ in the range of 0.8 to 0.9. In general, the curves show a sharp increase in nutrient removal during the first 5 to 15 days, followed by a more gradual increase with longer detention times. After 100 days of detention time, the removal rate for phosphorus and nitrogen was 75% and 42%, respectively.

- The Harper detention time equation was used to define the expected Treatment Volumes for the proposed Virginia Level 1 and 2 Wet Pond sizing criteria (i.e., 1.0 inch and 1.5 inches, respectively). The resulting detention times were then inserted into the Florida nutrient mass removal equations to obtain a prediction of nutrient removal rates under the proposed Virginia design criteria, as shown in **Table 6-C.6**. Since the Harper detention time equation was developed using Florida ponds, it is not recommended as a hard rule for setting a minimum detention time for ponds in Virginia. However, it does provide additional evidence that groundwater-influenced wet ponds sized according to the new Virginia design specifications have limits on their maximum expected nutrient removal rates. Specifically, the proposed pond sizing criteria appear capable of surpassing Level 1 phosphorus removal rates (50%), but cannot achieve the Level 2 rate of 75%. In the case of nitrogen, the proposed sizing criteria can only meet Level 1 nitrogen removal rates (30%) when ponds are sized to Level 2 design (e.g., 1.5 inches).

***Table 6-C.6. Predicted Nutrient Removal Based on Harper Pond Equation***

| VA DEQ Wet Pond Criteria | Wet Pond Sizing Criteria | Annual Detention Time [1] | Predicted P Mass Removal (%) [2] | Predicted N Mass Removal (%) [3] |
|---|---|---|---|---|
| **Level 1** | $T_v$ = (1.0) (Rv) (A) / 12 | 9 days | 55 | 10 |
| **Level 2** | $T_v$ = (1.5) (Rv) (A) / 12 | 13.5 days | 58 | 33 |
| [1] page 5.34<br>[2] page 5.38<br>[3] page 5.39 | | | | |

Source: Equations in Harper and Barker (2007)

- Harper and Baker (2007) also address the issue of pond stratification and depth, which is at the heart of the groundwater-$T_v$ exclusion debate. The authors are unambiguous on this point – the depth of a coastal plain Wet Pond (including the depth below groundwater) by itself is not a particularly useful design parameter. This conclusion is also reinforced by an independent study of Florida ponds by Ceilla and Everham (2008).

- The authors note that the key pond design issue is actually the trophic state of the pond. This determines the depth of the anoxic zone, which increases nutrient release from the sediments. The trophic state is a measure of the degree of eutrophication in a pond which, in turn, is a function of the pond's nutrient input and residence time. Residence time is expressed as the pond pool volume divided by the annual runoff input from its catchment. Thus, pool depth is not always a reliable indicator of a longer detention time. Indeed, based on prior limnological research, there may be cases where a deeper pond could have a longer detention time (and be less eutrophic) than a shallow pond.

- Based on Florida pond and lake data, Harper and Barker (2007) present an equation to estimate the depth of the anoxic zone (see Page 6.48 of their work). When this equation is solved for typical trophic data reported by Drescher et al (2007) for South Carolina coastal Wet Ponds (pond chlorophyll-*a* of 40 ug/l; pond TP of 0.10 mg/l; pond TN of 1.0 mg/l; and an assumed Secchi depth of 1 foot), it implies a typical anoxic zone for coastal plain Wet Ponds of about 1 foot.

- Several other recent studies have shed light on the behavior of coastal plain Wet Ponds. The first is a comprehensive review by Drescher et al (2007) that describes a baseline study of 112 South Carolina Wet Ponds, and a review of data from other coastal plain states. The baseline study indicated that while dissolved oxygen (DO) was low in the coastal ponds, it was generally greater than 4.0 mg/l in 80% of 110 ponds evaluated. The coastal ponds were eutrophic to hyper-eutrophic with respect to chlorophyll-*a* concentrations (32% of ponds had chlorophyll-*a* > 40 ug/l). A majority of hyper-eutrophic Wet Ponds (chlorophyll-*a* > 60 ug/l) contained harmful algal blooms (HABs). In many cases, the limiting nutrient within coastal Wet Ponds was nitrogen rather than phosphorus, particularly when groundwater was brackish or the pond was tidally influenced.

- The HAB issue was further evaluated by DeLorenzo and Fulton (2009) who documented the presence of a wide range of HABs in coastal Wet Ponds, including blue green algae blooms (*cyanobacteria*), dinoflagellate blooms such as *Pfiesteria*, and "red tides," and raphidophytes. While the presence of algal blooms indicates that Wet Ponds are working to reduce nutrients, HABs can release toxins that can kill fish, contaminate shellfish and, in some cases, affect human health. HABs are most pronounced in Wet Ponds that have brackish groundwater and/or are directly connected to tidal waters [where salinity is > 5 parts per thousand (ppt)]. DeLorenzo and Fulton (2009) note several examples where HABs in hyper-eutrophic Wet Ponds were exported to adjacent tidal waters.

- Another set of studies evaluated the condition of large populations of Wet Ponds as they were actually installed and maintained in coastal plain conditions (Hirschman and Woodworth, 2009, and North and South Carolina studies summarized in Drescher at al, 2007). Most of the Wet Ponds were built according to pre-2000 design standards. Field evaluations indicated that a large fraction of the Virginia, North Carolina and South Carolina Wet Ponds fail to meet minimum design recommendations/guidelines with respect to forebay installation, minimum length-to width-ratio, and aquatic benches, and that many were encountering functional problems relating to a lack of maintenance (sediment deposition, excessive plant growth, trees on the embankment, etc.).

- In both South Carolina and Virginia, the worst performing Wet Ponds were in commercial areas rather than residential areas, which may reflect the fact that they were squeezed into the sites and had small contributing drainage areas. Indeed, anecdotal evidence from several designers at the March 2009 Stormwater Charette Design Workshop in Tidewater Virginia indicated that shallow Wet Ponds with small contributing drainage areas frequently produced the most nuisance conditions and maintenance problems.

### 6-C.6.2. Implications for Coastal Plain Wet Pond Design

Wet Ponds can be considered an *acceptable* stormwater practice for use in the coastal plain where the water table is within 4 feet of the land surface. However, *Constructed Wetlands are a preferred alternative when space is available*.

***Adjustments to Nutrient Removal***. The numerous lines of evidence reviewed indicate that standard designs of coastal plain wet ponds *cannot* achieve the desired nutrient removal rates in the current Virginia Stormwater Design Specification for Wet Ponds, based on design criteria, detention times, the influence of groundwater, and other factors. Therefore, slightly lower nutrient removal rates are proposed for coastal plain Wet Ponds to reflect the real world performance data for phosphorus and nitrogen removal. Specifically, Level 1 and 2 total removal rates for TP are now proposed to be 45% and 65% respectively, and Level 1 and 2 TN removal rates are reduced to 20% and 30%, respectively. These slightly lower removal rates are supported by recent pond research and the detention time relationships.

***Essential Design Elements.*** The research validates the importance of incorporating specific Wet Pond design elements (e.g., forebays, minimum flow path, expanded wetland cover and multi-cell construction) to achieve desired nutrient removal performance. Given their importance in promoting nutrient removal, these factors are considered essential minimum design features for all Wet Ponds, as shown in **Table 6-C.4** above. Two additional design elements are recommended to distinguish Level 2 from Level 1 ponds, based on comments from designers and local stormwater managers. The first relates to pond landscaping to discourage geese. The second involves the use of internal mechanical devices to increase aeration and/or nutrient reduction..

***Remove Pool Depth Restrictions.*** The research suggests that there is no technical basis for reducing the Treatment Volume to account for groundwater inputs, even when the water table is high, once the overall nutrient removal rates are adjusted. Reliable removal can be achieved by groundwater-influenced ponds, if they achieve the detention time associated with the Treatment Volume sizing and contain the requisite internal design features to promote nutrient removal. There is some indication that, on average, about 1 foot wet pond pool depth will be anoxic in the summer, which is accounted for in the slightly reduced maximum nutrient removal rates.

***Restrictions on Brackish Ponds***. Wet Ponds are discouraged in cases where groundwater input to the pond is brackish or is hydraulically connected to tidal waters [where salinity is > 5 parts per thousand (ppt)]. Given the potential for strong association of HABs with hyper-eutrophic Wet Ponds, it may not be wise to allow ponds to intersect the water table when (1) it is brackish and (2) there are other nutrient sources in the contributing drainage area (e.g., golf courses, septic systems, land application of biosolids).

***Pocket Ponds***. Another issue relates to Wet Ponds with small contributing drainage areas that are solely supplied by runoff and groundwater, frequently resulting in nuisance conditions and fluctuating water levels. There is virtually no data on these “pocket ponds” that are often installed on small commercial sites. Rather than mandating an arbitrary minimum drainage area, it is recommended instead that these pocket ponds must meet the minimum design and geometry requirements for all ponds (i.e., having a sediment forebay cell, aquatic benches, maximum side-slopes of 5W:1H, and a length-to-width ratio of 1:1).

In addition, the pond water balance evaluation must demonstrate that the pond will not draw down more than 2 feet during a 30-day summer drought, using the pond drawdown equation in (Equation 14.1 in Virginia Stormwater Design Specification No. 14: Wet Pond). Designers should strictly adhere to the same design requirements that apply to other Wet Ponds, which should greatly reduce the number of nuisance ponds that are forced into too-small sites (i.e., by reducing or eliminating essential pond design elements).

***Increasing Runoff Reduction for Water Re-Use Ponds***. Several designers noted that the guidance neglected the possibility of achieving runoff volume reduction from ponds through water re-use (i.e., pumping pond water back into the contributing drainage area for use in seasonal landscape irrigation). While this practice is not common, it has been applied to golf course ponds, and accepted computational methods are available (Wanielista and Yousef, 1993 and McDaniel and Wanielista, 2005). It is recommended that designers be allowed to take credit for annual runoff reduction achieved by pond water re-use, as long as acceptable modeling data is provided for documentation.

***Benchmarking Sediment Deposition in Coastal Ponds***. To facilitate maintenance, the contractor must mark and geo-reference on the as-built drawing the actual constructed depth of three areas within the permanent pool (forebay, mid-pond and outflow). This simple action will enable future inspectors to determine pond sediment deposition rates and schedule sediment cleanouts, as needed.

## 6-C.7.0. ACKNOWLEDGEMENTS

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For more in-depth guidance related to managing stormwater in a coastal setting, see the Georgia Department of Natural Resources' *Coastal Stormwater Supplement to the Georgia Stormwater Management Manual,* prepared by the Center for Watershed Management (http://www.cwp.org/Resource_Library/Center_Docs/SW/georgia_css.pdf).

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